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ABSTRACT

High school students learn about the sun's effects on the earth by examining the concepts of latitude and longitude, seasons, and time. Each of these topics is treated in a separate, but similarly organized, unit. Relevant vocabulary is introduced, and complex terms are clarified with diagrams and illustrations. In the unit on time, potentially confusing concepts such as standard time and the International Dateline are given extra attention. Each lesson features a set of application problems, including drawing exercises, to measure students' understanding of the material. A special section of more difficult questions is provided for use with advanced classes. Answer keys, with explanations, are included. (LP)

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Earth-Sun Relationships
Latitude, Longitude and Time

Paul F. Thomas

A. REASONS FOR STUDYING THIS TOPIC

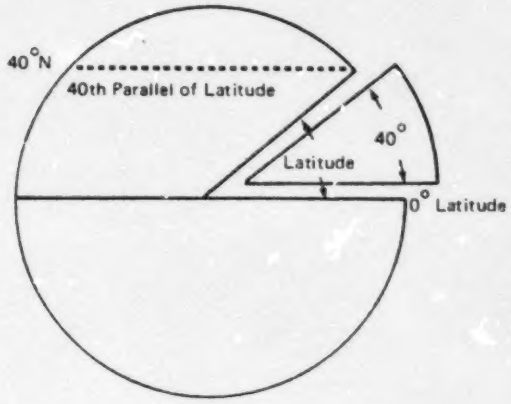
1. Earth's *rotation* (about its axis) + earth's *revolution* (movement around the sun) + earth's *inclination* of its north-south axis (23½° from the vertical) are responsible for the facts of:
   a. day and night;
   b. changes in length of day and night throughout the year;
   c. the seasons.
2. More specifically, the sun's direct rays, through the seasons, fluctuate between 23½° N and 23½° S, causing variations in the amount of *insolation* (heat energy) received from the sun.
3. *Latitutde* and seasons are the chief indicators of solar insolation, which in turn determines variations in climate, and the subsequent variations in vegetation and possibilities for human and animal life.
4. In other words, man's connection with the natural environment begins with his relationship to the sun as expressed through changing planetary position.
5. Longitude lines are meridians (Latin for "mid-day lines"); that is to say all points on a given meridian experience mid-day (noon) at the same time. Longitude and clock time are therefore related to one another.

B. LATITUDE AND LONGITUDE

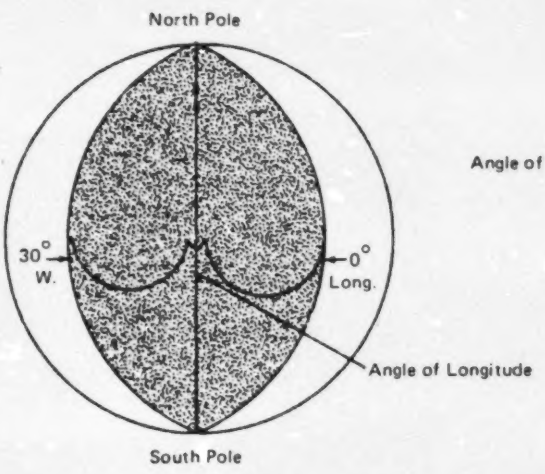
The essential concepts can only be conveyed through graphic illustrations and/or planetary models. Please remember that *latitude is an angle* not a line because it is measured in degrees. A line joining points having the same latitude (angular distance north or south of the equator) is known as a *parallel of latitude.*

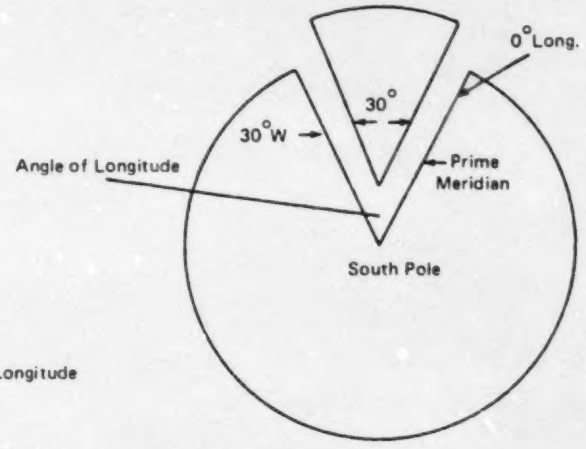
Diagrams to illustrate these ideas must be drawn using compasses and protractor by both teacher and students, if the various relationships are to be properly understood. Blackboard compasses and protractor can usually be obtained from the mathematics or shop teacher.

Latitude: is the angular distance north or south of the equator.



Line of Latitude. joins points having the same latitude.



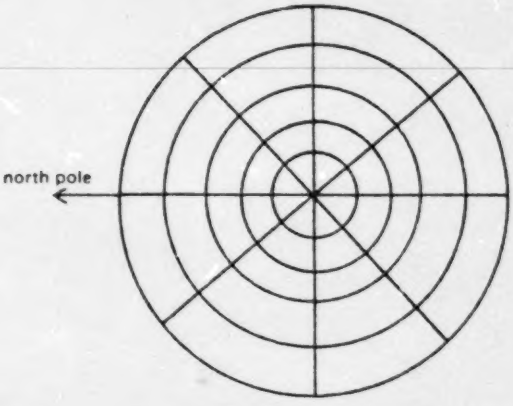


Longitude: is the angular distance east or west of the prime meridian.

Line of Longitude: joins points having same longitude—also known as a meridian, it joins places having same sun time (literally mid-day at same time.)

LATITUDE AND LONGITUDE LINES COMPARED

Latitude Lines	Longitude Lines
1. Run east-west.	Run north-south.
2. Join points having the same angular distance north or south of the equator.	Join points having same angular distance east or west of the prime meridian.
3. Measure angular distance north-south.	Measure angular distance east-west.
4. Are numbered 0°-90°.	Are numbered 0° to 180°.
5. Are parallel, concentric circles.	Meet at the poles.
6. Cross longitude lines at right angles.	Cross latitude lines at right angles.
7. Get shorter towards the poles.	Are of equal length.
8. Only the equator is a great circle.	Are all great circles (for instance, equal to circumference of the earth).
9. Lie in planes which cut the earth's axis at 90°.	Are also time-lines known as meridians.
10. The equator is a natural, special line and cuts the world into northern and southern hemispheres.	No longitude line is naturally special. The line through Greenwich, England, for convenience, is designated 0°, and prime meridian. Any other longitude line could have been chosen for that purpose.
11. Latitudinal position can be determined by a SEXTANT.	Longitudinal position can be determined by a CHRONOMETER.

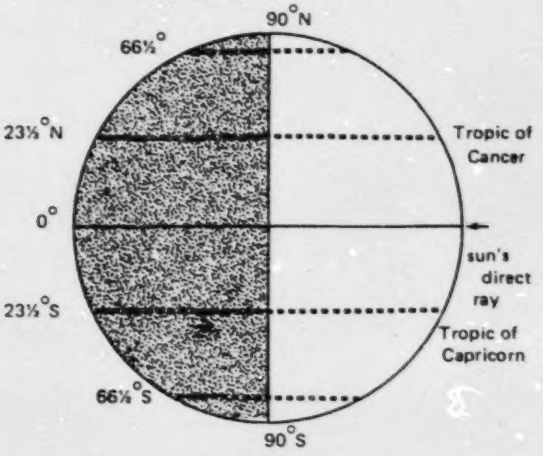


APPEARANCE OF GRID LINES AS VIEWED FROM NORTH POLE (OR SOUTH POLE)

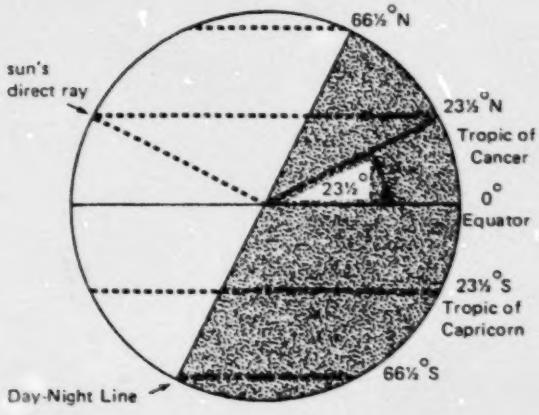
Latitude lines appear as concentric circles; for instance, circles having a common centre, about the pole.

Meridians appear like the spokes of a wheel passing through the pole. The intersection of grid lines at right angles is also apparent.

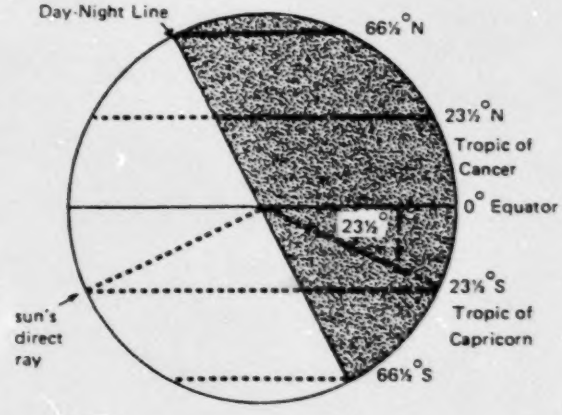
C. EARTH-SUN RELATIONS AND THE SEASONS



Equinox—September 21 and March 21
Day-night line coincides with earth's axis.



Summer Solstice—June 21



Winter Solstice—December 21

Basic Terms Used in Speaking of the Seasons

Axis
Line joining north pole to south pole.

Summer Solstice
Time of longest day and shortest night.
June 21 (first day of summer).
Sun's direct ray falls on 23.5°N.
Day-night line touches polar circles.

Winter Solstice
Time of shortest day and longest night.
December 21 (first day of winter).
Sun's direct ray falls on 23.5°S.
Day-night line touches polar circles.

Equinox
Time of equal day and night.
September 21 (first day of fall).
March 21 (first day of spring).
Sun's direct ray falls on equator.
Day-night line cuts all latitude lines in half.

Polar Circles
Antarctic circle = 66.5°S
Arctic circle = 66.5°N
Note: 66½° = 90° - 23½°
lines touched by SDR at solstices

Tropic of Cancer = 23.5°N
Tropic of Capricorn = 23.5°S
mark farthest northern and southern movements of the sun's direct ray

Tropics
Area between 23.5°N and 23.5°S within which all movements of sun's direct ray (SDR) occur.

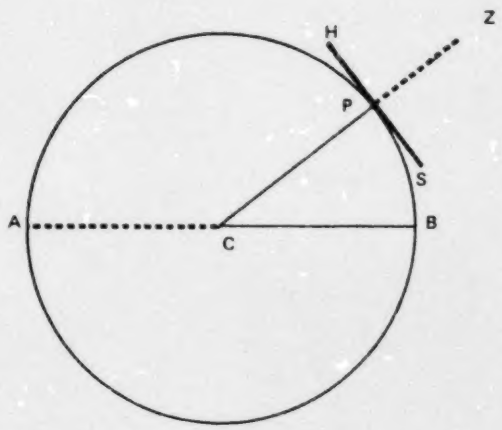
Sun's Direct Ray (SDR)
The ray which points to centre of earth.

Rules for Drawing "Season" Diagrams
—Plane of equator passes through centre of circle.
—Measure angle of latitude with protractor.
—Parallel of latitude is parallel to equator.
—*Sun's direct ray*, if projected passes through centre of earth.
—*Day-night* line is drawn through centre of circle at right angles to projected sun's rays.
—A line joining centre of circle to the observer, which is projected into space, is called the *Zenith* of the observer.
—The *horizon* is the tangent at the point where

observer is standing drawn at right angles to the Zenith.

—Day-night line just touches polar circles during the solstices.

Visual Review



P = position of observer
C = centre of earth
AB = equator

Questions

i. What is latitude of P?
ii. What is Zenith of P?
iii. What is horizon for P?

Note that: HS = horizon for P; = tangent at P; = meets radius CP at 90°. PZ = Zenith for P; = radius CP extended outwards into space. PC = plumb line or "down" for person standing at P.

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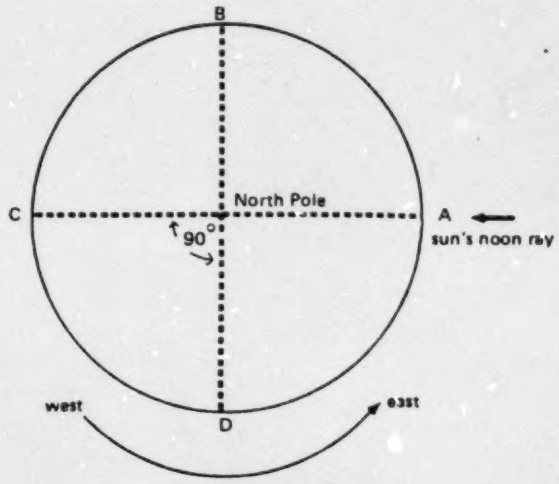
iv. On what dates will the sun be on the horizon at the north pole?
v. When is the sun in the zenith for Vancouver?
vi. When does the day-night line coincide with the earth's AXIS?
vii. What angle does the day-night line make with the earth's axis during the solstices?
viii. How can we tell if a sun's ray is direct?

Answers

i. <PCB.
ii. PZ = "up" for observer standing at P.
iii. HS.
iv. The equinoxes—March 21, September 21.
v. *Never.* The sun can only be overhead, on or between the tropics.
vi. At the time of the spring or fall equinox.
vii. 23½°. As the overhead (zenithal) sun moves 23½° away from the equator, the day-night line moves the identical angular distance 23½° away from the earth's axis; so as to just touch the polar circles at 66½°N and S. Note that 66½° = 90° - 23½°.
viii. When the sun is in the zenith, a direct ray will, if extended, appear to pass through the centre of the earth.

D. LONGITUDE AND TIME

1. Angular Distance and Time Difference



The above diagram represents the rotation of the earth as seen from the north pole. Since the sun appears to rise in the east each morning, the earth rotates so as to meet the rising sun, that is from *west to east*. Points east experience sunrise before points west do. Similarly points east experience noon before points west do.

In the diagram, *A* is experiencing noon. All points having the same longitude as A, will experience noon at the same time.

a. B is on the opposite side of the globe from A. What is the time at B? (Answer: the opposite time to noon is midnight.)
b. How long will it take for A to experience noon again? (Answer: The time that it takes for the earth to rotate about its

axis to bring A back to its present position. The length of such a complete rotation is one day or 24 *hours*.)

c. What is the angular distance that A will pass through in 24 hours? (Answer: One complete rotation means the completion of one full circle of motion; for instance, an angle of 360°.)

d. What is the angular distance that A will traverse in one hour? (Answer: In 24 hours A traverses 360° of longitude. In one hour A traverses $\frac{360°}{24}$ = 15° of longitude.)

Rule

A time difference of one hour " an angular distance of 15° and vice versa.

Application

In the preceeding diagram, if it is noon at A, what is the time at:

a. B?
b. C?
c. D?

Answers

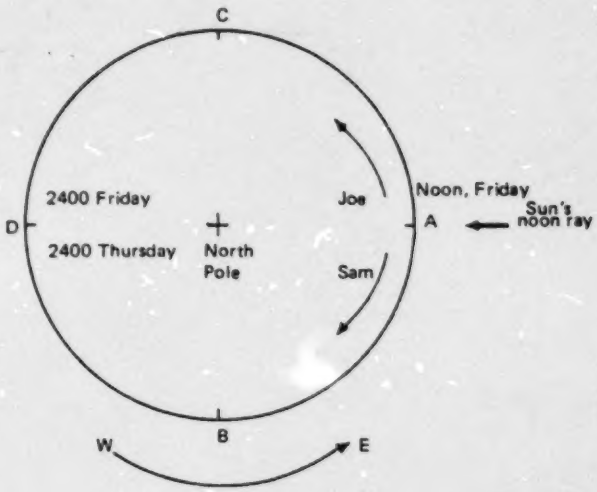
a. Angular distance between A and B = 90° of longitude.
   15° of longitude → one hour of time
   90° of longitude → $\frac{90}{15}$ → six hours of time

   Since B is east of A it has already passed through noon. Therefore time at B = noon + six hours; = 6 pm or 1800 hours.

b. Angular distance A to C = 180°.
   15° → one hour
   180° → $\frac{180}{15}$ → 12 hours
   Time at C = noon + 12 hours = midnight or 2400 hours.

c. Angular distance A → D = 90°.
   90° → six hours of time
   D is moving towards noon, but is six hours short of noon. Time at D = noon - six hours = 6 am or 0600 hours.

2. A Quirk in Time



Joe and Sam are at point A, on noon Friday. They decide to take a trip around the world in opposite directions as shown on the diagram; so that Joe travels eastward and Sam travels westward. If they can travel with the virtually instant speed of light, when will they arrive at D? (Answer: In travelling eastwards to D, Joe traverses 180° and gains $\frac{180}{15}$ or 12 hours. He therefore arrives at D at 2400 hours Friday. (Noon, Friday + 12 hours.) Sam, in travelling westward, similarly passes through 180°, but loses $\frac{180}{15}$ or 12 hours, so as to arrive at D at 2400 hours of the previous day, Thursday. (Noon, Friday - 12 hours = 0000 hours Friday; = 2400 hours Thursday.)

3. International Date Line

To prevent the absurdity of Joe and Sam not being able to meet on the same day, the *International Date Line* (IDL) was created. In going east, one gains time; in going west one loses time. Think of the IDL as a customs border-crossing where gains and losses are set to rights. In other words, gained time is surrendered; lost time is restored.

In the previous example, if D were on the IDL, Joe would surrender a full day to meet Sam; or Sam would gain a full day to meet Joe. *A full day is gained or lost when crossing the IDL, depending on the direction in which one is travelling.*

The rule is as follows:

Going west is best.
Going east is least.

In other words, in crossing the IDL going westwards a day is gained. In crossing the IDL going eastwards a day is lost.

Note that this rule is opposite to the one for crossing ordinary time-zones; where one loses one hour for each time zone going west, and gains one hour for each time zone going east. At the IDL, all gains and losses are wiped out. If that were not so, one could absurdly gain several days by repeatedly circling the world in a fast jet plane.

The IDL, by international agreement falls on 180° longitude (where 180°E = 180°W), which is 12 hours removed from 0°, the Greenwich meridian. The IDL is somewhat irregular so as to take in certain islands otherwise one side of a small territory would be a day apart from the other side, thus posing problems of communications in every day business-life.

4. Standard Time

Consider the diagram below. Suppose that the sun's noon ray is falling on Ottawa. Since Ottawa is at 75°W, all points on 75°W are experiencing noon at this time as well.

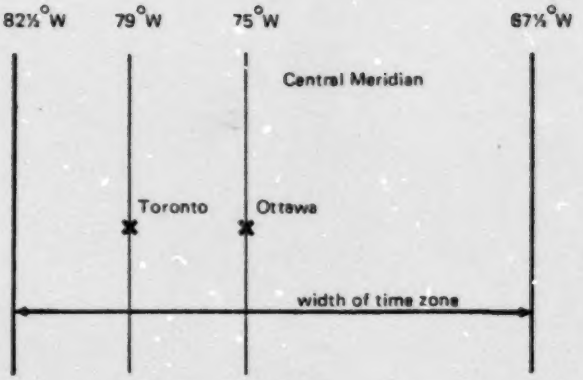
Consider also Toronto. Since Toronto is at 79°W it has not yet been touched by the sun's noon ray, falling on Ottawa.

When will Toronto experience noon? Angular distance Toronto - Ottawa = 79°W - 75°W = 4° of longitude.

We know that 15° of longitude → one hour or 60 minutes of time therefore 4° of longitude → $\frac{4}{15}$ of 60 minutes → 16 minutes. Toronto will experience noon 16 minutes later than Ottawa. But how is that possible? Toronto and Ottawa keep the same *clock time.*

Yes, that is precisely the point. *Clock time* and *sun time* are not the same.

Every single meridian experiences noon at its own unique sun time. The west end and east end of a town or city can not then have the same sun time.



To avoid the confusion that could result, time is standardized so that all places within a belt of 15°, known as a time zone, agree to keep the same clock time. The clock time so kept is the sum time of the central meridian in the time zone, which is always a meridian exactly divisible by 15°. (Remember 15° → one hour.)

In the diagram, the time zone containing Ottawa and Toronto extends from (75°W + 7½°) to (75°W - 7½°); for instance, 82½°W to 67½°W. (2 x 7½° = 15° → one hour).

The boundaries of the time zone are often a little irregular so that complete cities, islands and states can be included to avoid confusing people living near territorial borders.

Since each time belt is 15° wide, there will be 24 such belts in the world. (Recall: 24 x 15° = 360°. One complete earth rotation requires 24 hours.)

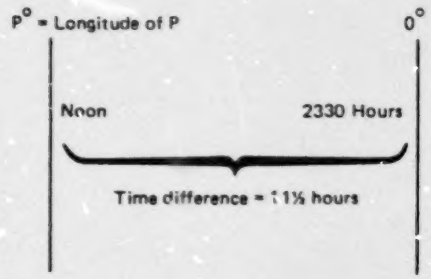
5. Problems in Longitude and Time

Because of the possibility of translating angular distance into time-difference and vice versa, ship navigators carry a very precise clock known as a *chronometer*, which keeps the exact time of a known reference point, usually that of the Greenwich meridian for which the clock time and sun time would be identical. (Why identical? Answer: because clock time = the sun time of a central meridian.)

Example (Simple)

What is the longitude of a ship experiencing noon, sun time, if the ship's chronometer is showing 2330 hours Greenwich Mean Time (GMT).

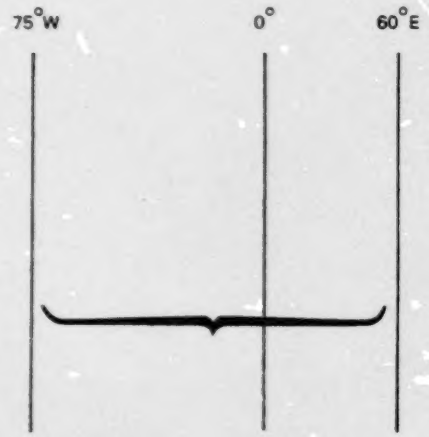
Solution
Always draw a sketch. Determine whether observer is east or west of reference on basis of whether time is earlier or later. In this case P's time is earlier so he/she is to west of 0°.



From the sketch, time difference between observer P and 0° = 2330 - 12 = 11½ hours. Angular distance between P x 0° = 11½ x 15° = 172½°. Since P's time is earlier than that at 0°, he/she is to the west of Greenwich. Longitude of P is therefore 0° - 172½° = 172½°W.

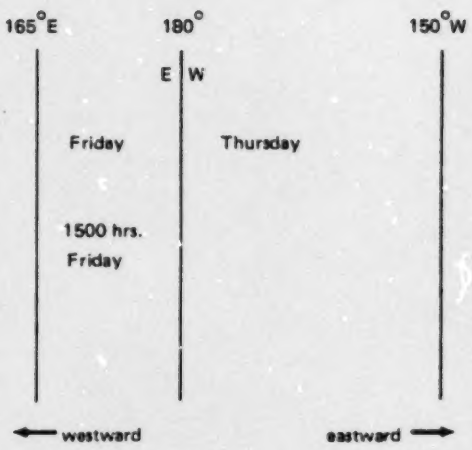
Examples (Complex)
The use of sketches will simplify the most complicated situations. If the reference meridian is not 0° be sure to draw in 0° and 180° where applicable.

a.



From the sketch it is obvious that the angular distance between 75°W and 60°E is (75° - 0) + (60° - 0) = 135°. The corresponding time distance between 75°W and 60°E = $\frac{135}{15}$ or nine hours.

b.



From the above note that:

i. Angular distance 165°E to 150°W = (180 - 165) + (180 - 150) = 15° + 30° = 45°.

ii. Time distance 165°E to 150°W | $\frac{45°}{15}$ = three hours

iii. Going west is the same as reducing degrees of eastness from 180°E to 165°E. Going east is the same as reducing degrees of westwardness.

iv. 179°E is west of 179°W; for instance, when 180° appears in sketch, E. and W. appear reversed from the position in which they appear when 0° is used.

v. If it is 1500 hours Friday at 165°E, what is the time at 150°W?
Solution: Only with aid of sketch is it apparent that:
150°W is to east of 165°E.
Three hours will be gained going to 150°W.
One day will be lost crossing 180° towards the east, thus time at 150°W = 1500 hours Friday + three hours - one day = 1800 hours Thursday.

E. For Enriched Classes

1. Problems in Longitude and Time
Complete the table provided. Each numbered line is a distinct problem. With the information provided, answers for the blank spaces can readily be computed, *with the aid of simple sketches*, as indicated earlier.

An answer key is provided separately.

PROBLEMS IN LONGITUDE AND TIME

	Sun time of observer, P	Reference meridian, R, for which chronometer is keeping time	Standard clock at R.	Angular distance between P and R	Time distance between P and R	Longitude of P
1.	1500 hours	0°	2200 hours			
2.		75°W	1200 hours			67½°W
3.	1430 hours		1830 hours			15° E
4.	Noon	Moscow 37°E	2115 hours S.T.			
5.	1200 hours (Friday)		1200 hours (Thursday)			180°E
6.	0800 hours (Monday)	165°E	0600 hours (Tuesday)			
7.	1515 hours	Delhi 77°E			(+) 4 hours	
8.		11½°W	0130 hours (Tuesday)			79°W
9.	1540 hours (Saturday)	90°E				75°W

PROBLEMS IN LONGITUDE AND TIME
Answer Key

	Sun time of observer, P	Reference meridian, R, for which chronometer is keeping time	Standard clock at R	Angular distance between P and R	Time distance between P and R	Longitude of P
1.	1500 hours	0°	2200 hours	time distance= 7 hrs. angular distance=7 x $15=105^\circ$ to west	1500–2200 hrs. = 7 hrs. earlier	$0 - 105^\circ = 105^\circ$ W
2.	1230 hours	75°W	1200 hours	75°W - $67\frac{1}{2}^\circ$W = $7\frac{1}{2}^\circ$ to eastward	$\frac{7\frac{1}{2}}{15}$ = ½ hr. later	$67\frac{1}{2}^\circ$W
3.	1430 hours	15°E + 60° = 75°E	1830 hours	4 x 15° = 60°	1430 - 1830 = 4 hours earlier	15°E
4.	Noon	Moscow 37°E (use clock time for 30°E)	2115 hours S.T.	9¼ x 15° = $138\frac{3}{4}^\circ$	1200 - 2115 = 9¼ hours earlier	30°E + $138\frac{3}{4}^\circ$ to west = $108\frac{3}{4}^\circ$W
5.	1200 hours (Friday)	180°W	1200 hours (Thursday)	180° - 180° = 0°	1200 Friday– 1200 Thursday = one day	180°E
6.	0800 hours (Monday)	165°E	0600 hours (Tuesday)	2 x 15 = 30°	0800 - 0600 = 2 hours to east, cross 180° lose one day	165°E + 30° = 165°W
7.	1515 hours	Delhi (keeps standard time of 75°E) 77°E	1515 - 4 hours = 1115 hours	4 x 15 = 60° to east	(+) 4 hours to east	75°E + 60° = 135°E
8.	0130 hours Tuesday - 4½ hours = 2100 hours Monday	$11\frac{1}{2}^\circ$W	0130 hours (Tuesday)	79° - $11\frac{1}{2}^\circ$ = $67\frac{1}{2}^\circ$	$\frac{67\frac{1}{2}^\circ}{15}$ = 4½ hrs. to west	79°W
9.	1540 hours (Saturday)	90°E	(Sat.) 1540 + 11 hrs. = 0240 (Sunday hours)	90° + 75° = 165°	$\frac{165}{15}$ = 11 hrs. earlier	75°W